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Precision Medicine and machine learning in Deep Brain Stimulation surgery for Parkinson's Disease: Ensuring individualized approach to improve efficacy

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Introduction and Motivation

- **Introduction**
  - Parkinson's Disease (PD): A neurodegenerative disorder with variable symptoms and treatment responses.
  - Deep Brain Stimulation (DBS): A standard therapy that modulates neural circuits to improve function.
- **Role of AI in addressing PD using DBS:**
  - Machine learning enhances DBS by optimizing treatment planning and execution, offering a transformative approach
- **Motivation**

  AI enhances DBS by optimizing planning, personalizing treatment, and improving outcomes, addressing variable responses and rising PD prevalence in MENA

- **Challenges**
  - Analyze the imaging to construct connectivity maps between the Subthalamic Nucleus (STN), Globus Pallidus internus (GPI), and cortical regions.
  - Improve the microelectrode recording to place the electrodes more precisely during deep brain stimulation surgery.
  - Improve the programming after surgery.

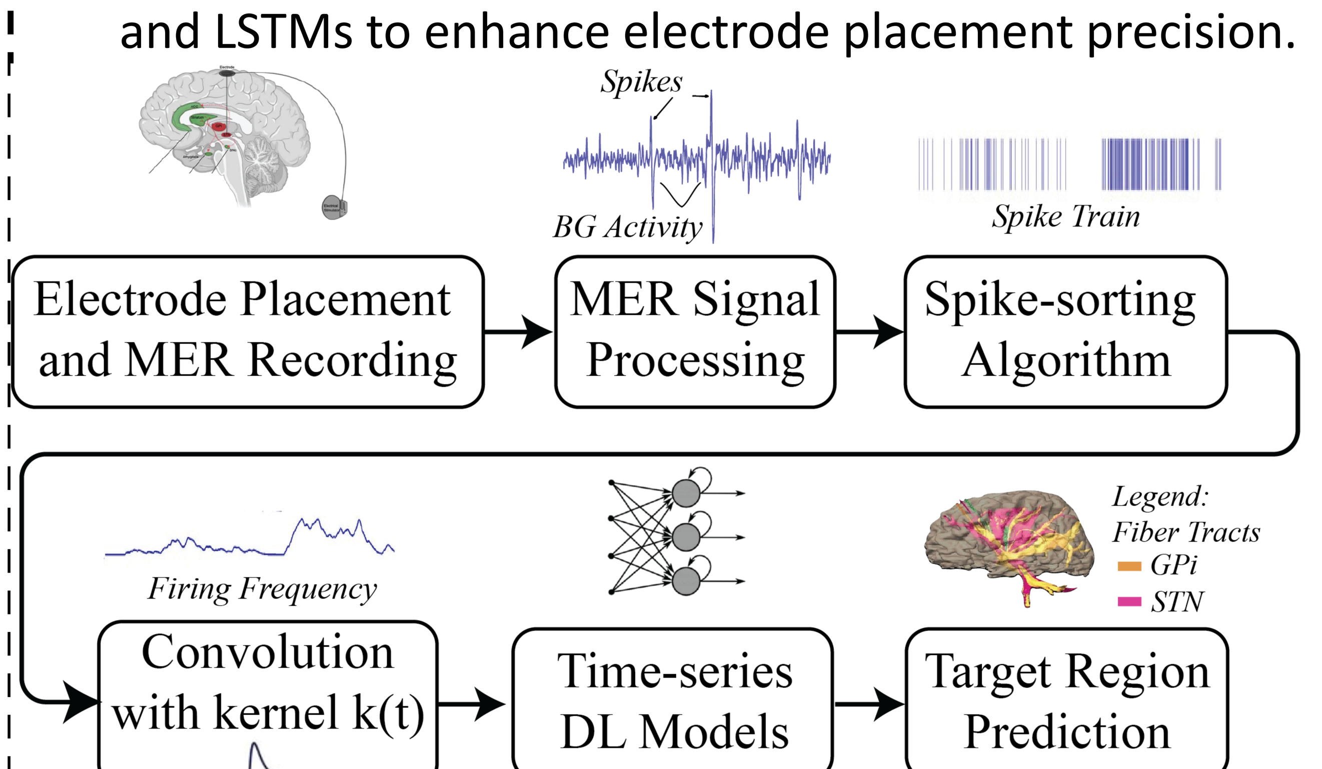
Novel Contributions:

- **AI-Driven Outcome Prediction**: Identifying key clinical and radiological features linked to DBS success.
- **Enhanced Lead Placement:** Machine learning models improve precision in electrode positioning.

- **Functionalities**
  - Patient Selection & Imaging: Identify DBS candidates and use MRI, DTI, and fMRI for brain mapping.
  - Intraoperative Data Collection: Record MER and LFP signals for neurophysiological mapping and spike-sorting.
  - AI-Driven DBS Optimization: Use ML to predict outcomes, refine lead placement, and adjust stimulation parameters dynamically.
  - Postoperative Evaluation: Cluster brain regions, augment data with PCA, VAEs, and GANs, and enhance interpretability with SHAP and LIME.
  - Personalized DBS Programming: Automate tuning to minimize clinic visits and use RL for safe, adaptive adjustments.

Proposed Methodology

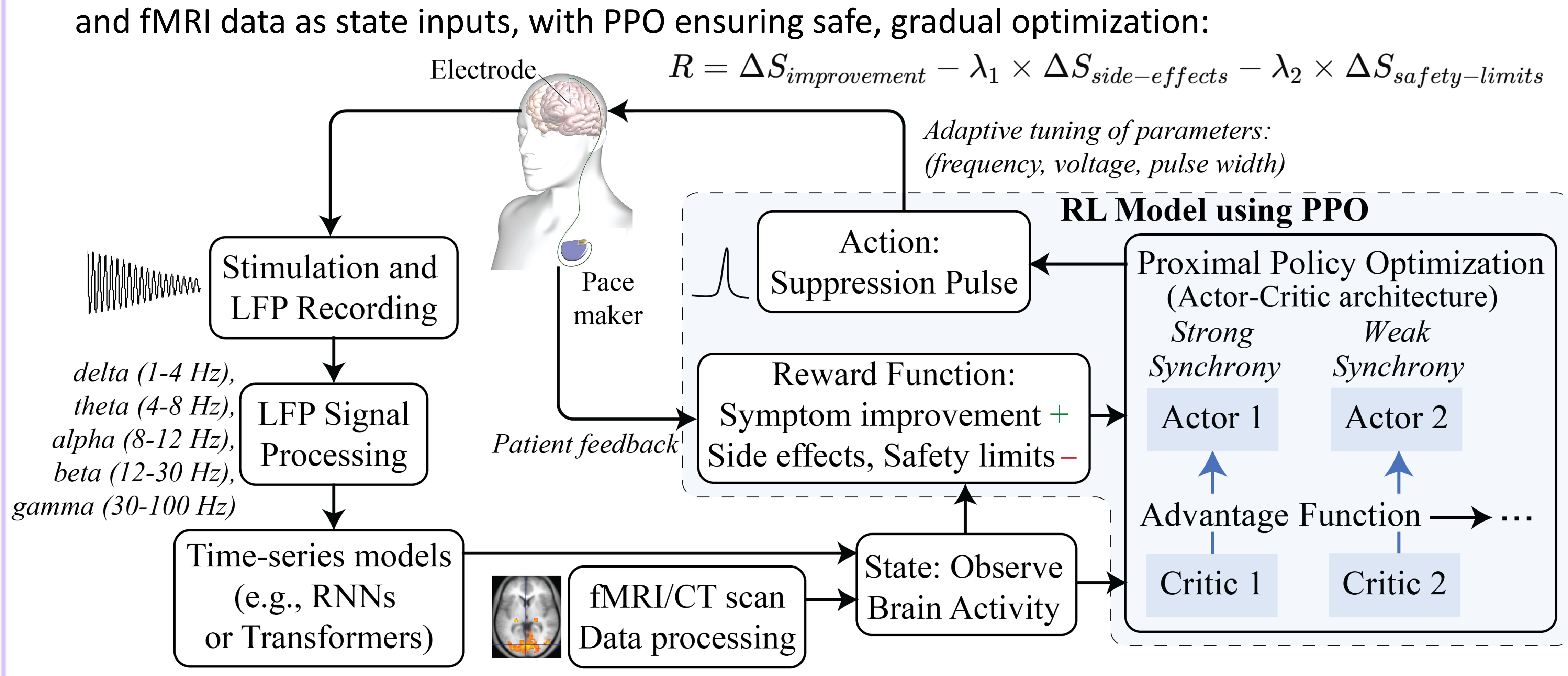
- **Pre-operative Phase:** DL models (CNNs, GNNs) will analyze MRI, DTI, and fMRI to map connectivity between STN, GPI, and cortical regions.
- **Intra-operative Phase:** Spike-sorting algorithms classify MER signals, integrating convolved spikes with RNNs and LSTMs to enhance electrode placement precision.



workflow for using MER during DBS surgery

- **Post-Operative Phase:** Reinforcement Learning (RL) dynamically adjusts DBS parameters using LFP and fMRI data as state inputs, with PPO ensuring safe, gradual optimization:

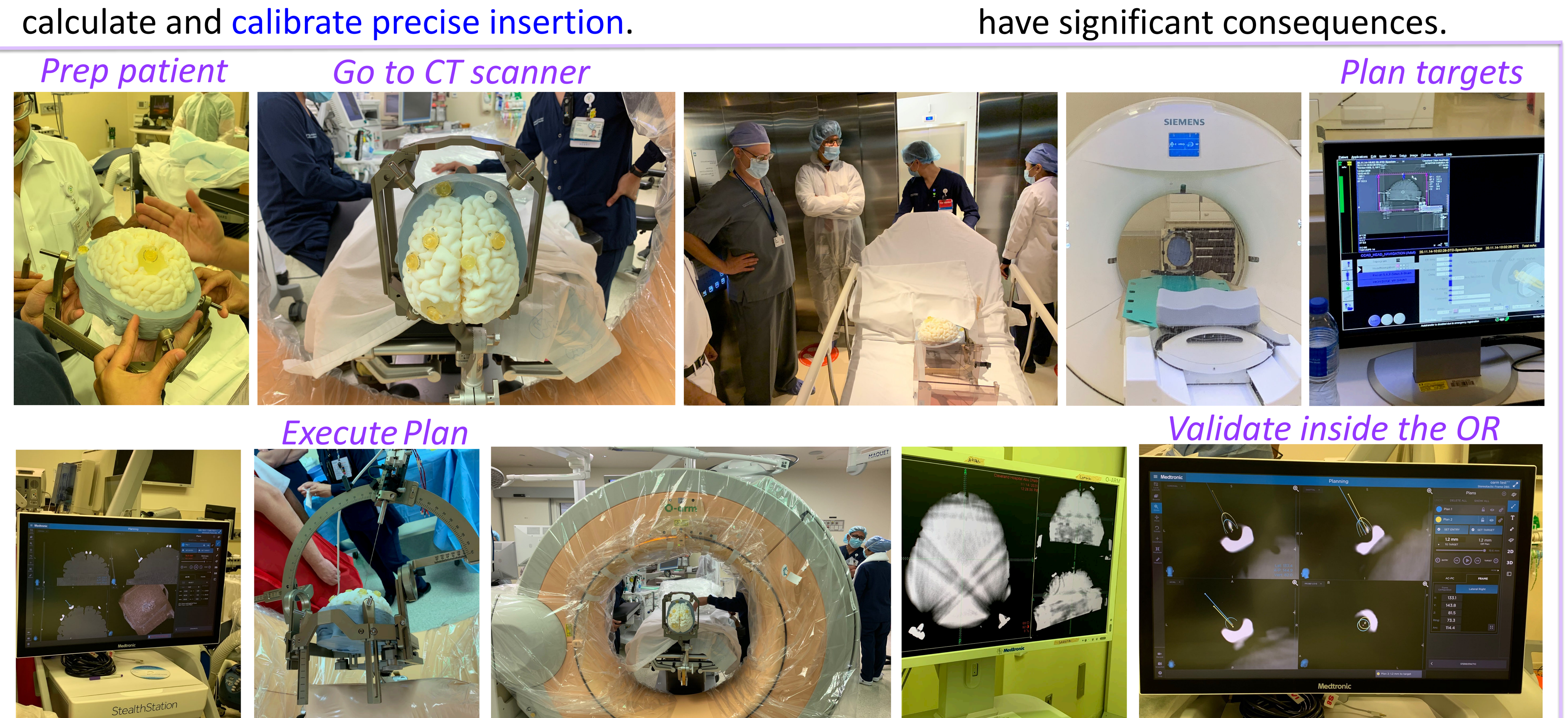
$$R = \Delta S_{improvement} - \lambda_1 \times \Delta S_{side-effects} - \lambda_2 \times \Delta S_{safety-limits}$$

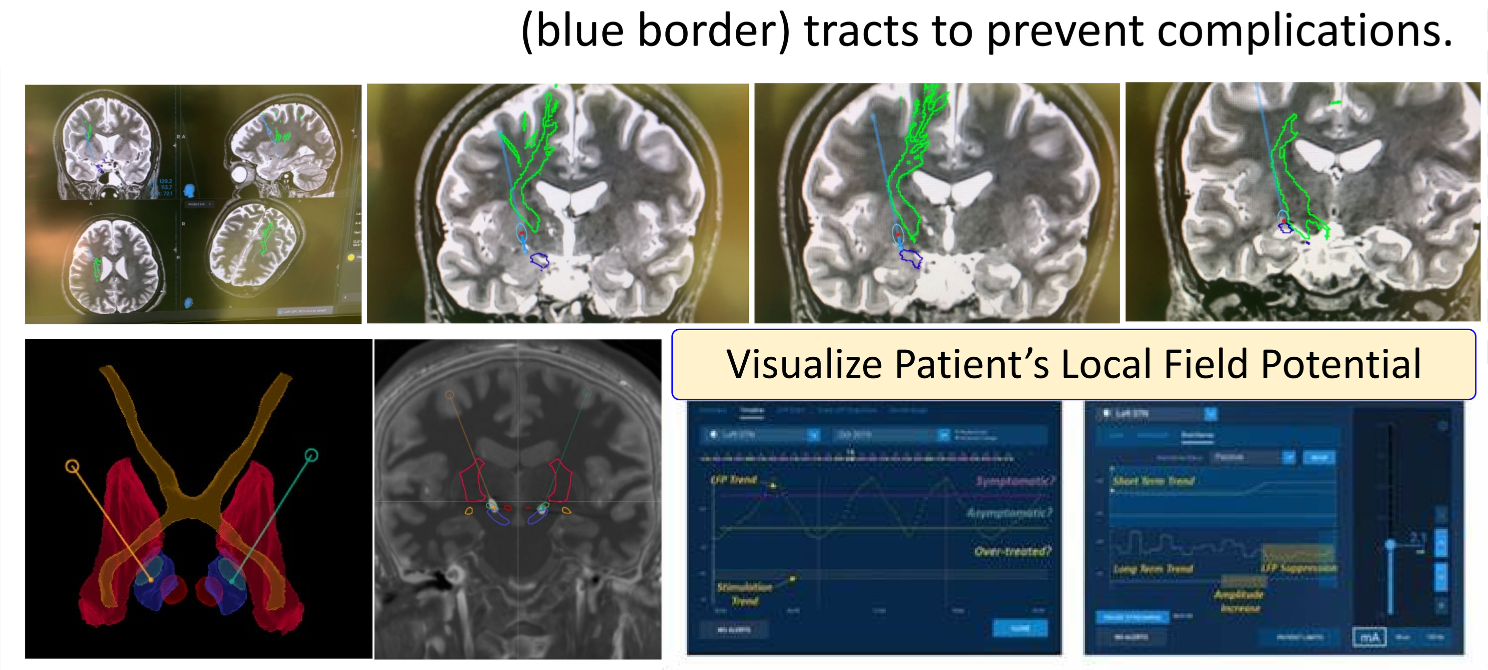


- Clustering algorithms will group brain regions by DBS response. PCA, VAEs, and GANs will augment data. SHAP and LIME will enhance interpretability, while diverse ML architectures will integrate multi-source data.

Feasibility and Proof of Concept Study

- **3D-Printed Brain Model:** A replica of patient's brain mounted in a skull stabilizer to simulate surgery.
- **Stereotactic Needle Placement:** Imaging used to calculate and calibrate precise insertion.
- **CT Scan Confirmation:** Post-insertion scanning verified needle position within a 1.2 mm margin.
- **Precision Matters:** Even small errors in the brain can have significant consequences.
- **DBS Lead Placement:**
  - The DBS lead trajectory (blue) targets the STN (red), avoiding the motor (green) and visual (blue border) tracts to prevent complications.





Conclusion:

- The DBS clinical workflow is complex, involving multiple specialists and clinical challenges. We aim to leverage machine learning to enhance planning and execution, ensuring precise, personalized treatment for PD patients.

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